

Power Plant on a Chip Moves Closer to Reality

AS yet, no battery in a laptop will last on a round-trip, coast-to-coast flight. Ditto for heavily used cell phones on a cross-country road trip. The comparatively short life of batteries and fuel cells is also an issue for the military, weapons-testing monitors, and the intelligence community.

But all that may be on the verge of changing. A team from the Laboratory's Chemistry and Materials Science Directorate and the Center for Microtechnology Engineering has been working for the past several years on a tiny device that can process minute amounts of fuel, such as hydrogen from methanol and water, to in turn feed a miniature fuel cell for powering unattended sensor systems and eventually consumer electronics.

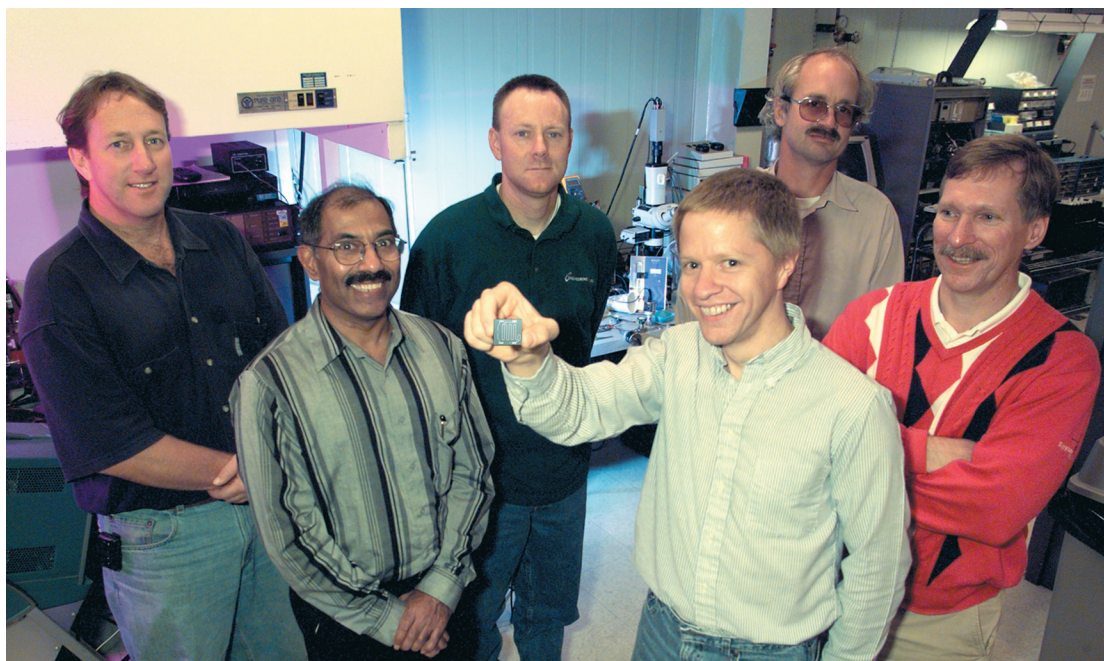
Power Hungry

We all get annoyed when our flashlights or handheld devices run low on juice. But it's a much more serious matter when the

electrical item in question is a sensor being used for remote military reconnaissance, intelligence gathering, or telemetry. Unattended sensor systems being developed for use by the military and homeland security require longer-lasting power sources than are currently available. Lawrence Livermore researcher Ravi Upadhye explains, "If you place a sensor for military or intelligence purposes, many times you cannot get back to it to renew the power. So not only does the sensor need to use very little power, but the power source also needs to last a long time."

The team's initial objective was to create a small power source that could generate about 500 milliwatts, or half of a watt, and operate at least three times longer than current rechargeable batteries. "We exceeded our objective by more than a factor of 10," says Upadhye. "A cell phone needs about 2 to 3 watts; we can keep one running with a single fuel cell for nearly 12 hours on a charge from about 25 milliliters of a methanol-water mixture."

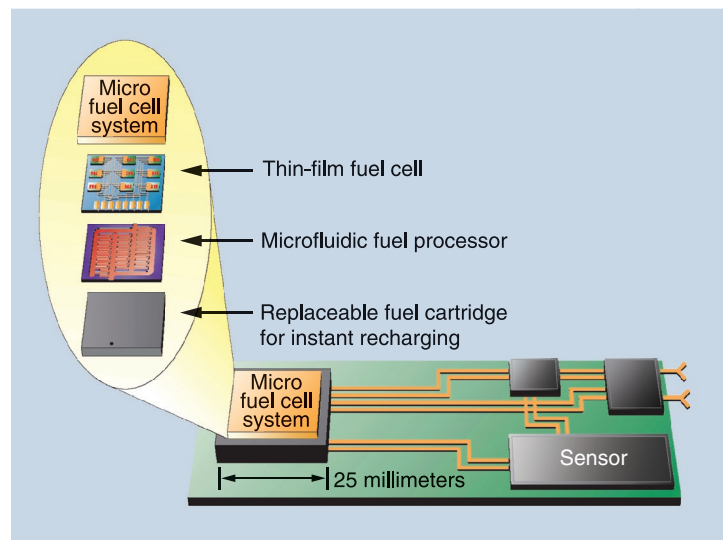
Fuel processor development team members (left to right): Jeff Morse, Ravi Upadhye, Tim Graff, Dave Sopchak (holding the dime-size processor), Mark Havstad, and Alan Jankowski.



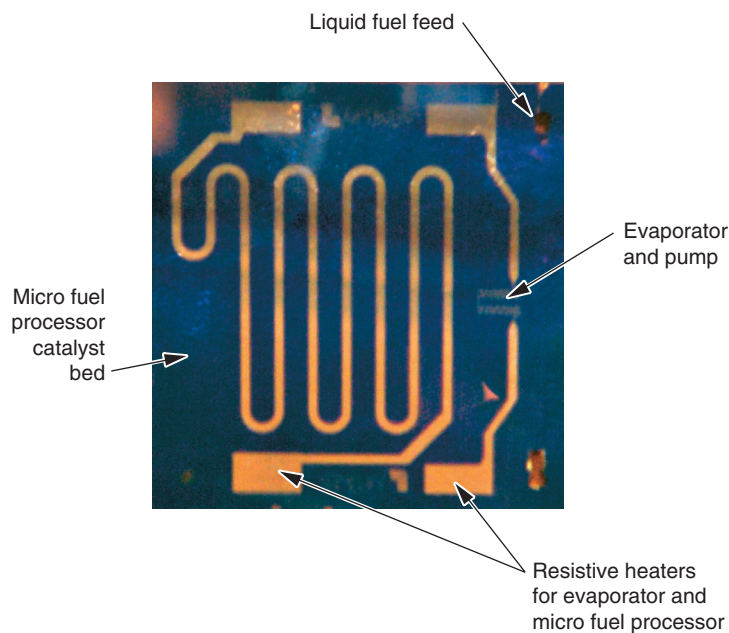
Making It Work

Fuel cells store energy in the form of an external fuel, rather than as an integrated part of the structure of the device, such as is in batteries. (See the [box on p. 20](#).) Upadhye led a team of chemists and engineers on a recently completed three-year Laboratory Directed Research and Development project to create a thermally robust, dependable microfluidic fuel processor that could be integrated into a Livermore-designed fuel cell system. The team successfully developed a dime-sized processor that converts methanol into hydrogen, which is used to power a thin-film fuel cell.

Methanol conversion to hydrogen was chosen because these new types of fuel cell systems need to operate from high-energy-density liquid fuels in order to stay small and reach the level of energy densities required. Schemes based on nickel-cadmium (ordinary batteries) don't provide much energy for the volume and weight taken up by the elements. Lighter-weight hydrogen could be used directly, but it does not provide the high energy densities required. Livermore's unique approach is to use a silicon micromachined catalytic fuel processor to convert high-energy-density hydrocarbon fuel (that is, methanol or butane) to hydrogen. Fifty milliliters of a fuel composed of 67 percent methanol in water now yields about 27 hours of "talk time" on a cell phone, or one to two months on standby.



This micro fuel cell system includes a Laboratory-designed microfluidic fuel processor that converts methanol and water (from a replaceable fuel cartridge) into hydrogen to power the thin-film fuel cell.



The dime-size fuel processor, up close, showing the various components. A methanol-water fuel is fed into the liquid fuel feed; tiny heaters heat the methanol mixture to produce hydrogen gas, carbon dioxide, and a small amount of carbon monoxide. The hydrogen fuel and ambient oxygen are delivered to the fuel cell manifold by microfluidic interconnects.

The 25-millimeter-square fuel processor is separate from the proton-exchange-membrane (PEM) fuel cell. The processor uses a reaction called steam reforming, in which a mixture of water and methanol snakes through microchannels the size of a human hair and coated or filled with a catalyst. When heated to nearly 300°C, the steam and methanol mixture reforms into hydrogen gas, carbon dioxide, and a small amount of carbon monoxide. The hydrogen fuel travels through microfluidic interconnects to the fuel cell manifold. Once in the fuel cell itself, the hydrogen combines with oxygen from the ambient air to produce electricity and water vapor. The entire steam-reforming reaction is sustained with only minimal power. The fuel processor, notes Upadhye, provides an integrated solution that solves the issues of fuel storage, processing, and delivery.

Over the past couple of years, Upadhye and the team successfully addressed a number of key technical issues. They simulated the reacting flow in the fuel processor to assist in the understanding and development of different processor designs. (See *S&TR*, [December 2001](#), pp. 4–11.) They made significant

Fuel Cell Basics

Take a simple physics experiment: send an electric current through water to split the water into hydrogen and oxygen components. Now, run that experiment backwards. Combine hydrogen and oxygen—the result? Water and electricity. Such was the reasoning of Sir William Grove, a British attorney and physicist in the mid-1800s. In 1839, he put this reasoning into the design of his gas voltaic battery, which is acknowledged today as the first fuel cell. And even though other fuels have been used—in 1889, for instance, chemists Ludwig Mond and Charles Langer attempted to build the first practical fuel cell using air and industrial coal gas—hydrogen-based fuel cells remain the primary focus of efforts to make small, practical fuel cells.

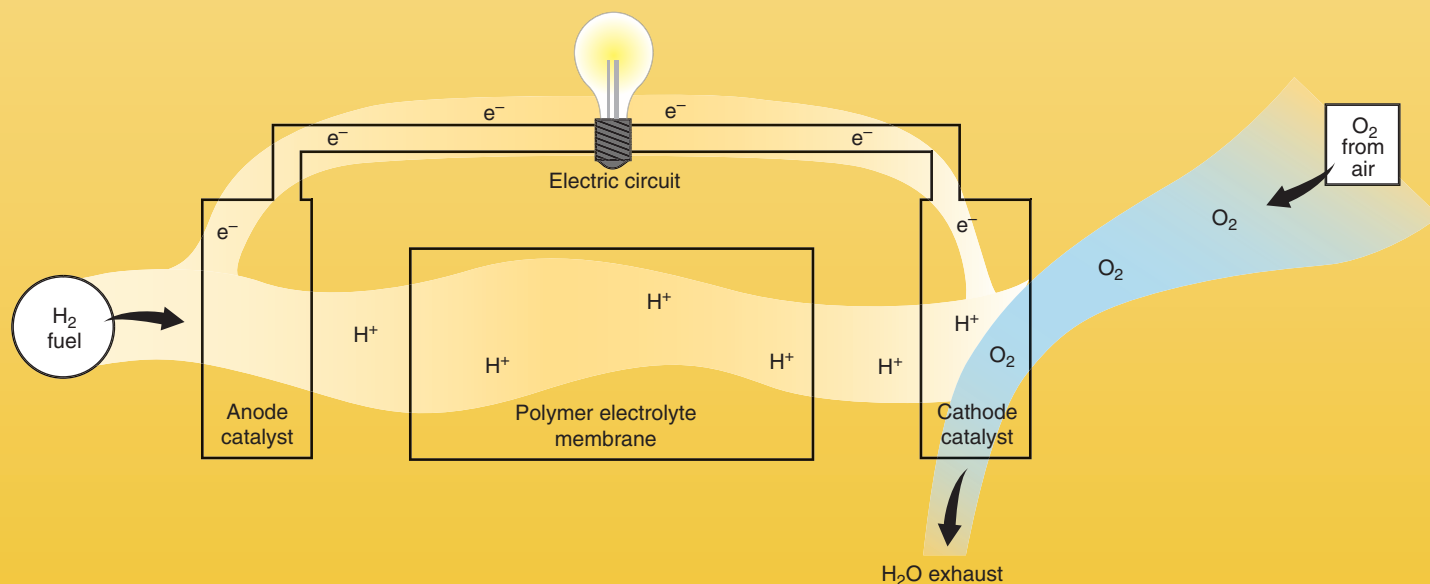
Fuel cells are electrochemical devices that convert the energy released by a chemical reaction directly into electrical energy. In a typical fuel cell, a gaseous fuel, such as hydrogen, is fed to the anode. At the same time, an oxidant, such as oxygen from the air, is fed continuously to the cathode. The fuel and oxygen meet at the electrodes, and the electrochemical reaction occurs. The resulting electrical current is delivered through current collectors.

Fuel cells are akin to batteries, but different in some fundamental ways. They have many components in common—

anodes, cathodes, and so on. And like batteries, fuel cells can be connected together in series to produce higher voltages. However, a battery stores its energy internally and has a fixed amount of material available for conversion to electricity. Once that material is depleted, the battery is useless or must be recharged. In a fuel cell, the fuel is stored outside the cell itself. Hence, a fuel cell has no fixed capacity—it will generate electricity as long as it is supplied with fuel and air.

Fuel cells can accept almost any kind of fuel, including gases such as hydrogen and methane, liquids such as gasoline, and solids such as carbon. Once connected to a fuel supply, a cell will produce electricity until its supply is removed or exhausted.

Fuel cells have been used in spacecraft and military applications for years. Livermore researchers are developing a number of types of fuel cells for different applications, including solid-oxide fuel cells (*S&TR*, September 2002, pp. 17–19), carbon conversion fuel cells (*S&TR*, June 2001, pp. 4–12), and the fuel cells described in this article, which use a proton-exchange membrane to combine oxygen and hydrogen to create electricity and water—a direct descendant of Grove's first fuel cell.



Anatomy of a micro fuel cell. The fuel cell looks like a sandwich, with the cathode and anode acting as bread to the electrolyte filling. Air (O_2) is drawn in through the cathode, and a gaseous fuel such as hydrogen (H_2) is drawn in through the anode. The cathode and anode (collectively called electrodes) are typically made of graphite or some other form of carbon. As the hydrogen passes through the catalyst, an electron (e^-) is stripped from each hydrogen atom. The hydrogen ions can then travel through the proton-exchange membrane. The electrons, meanwhile, travel through a circuit, creating an electric current. Electrons, hydrogen ions, and oxygen from the air all end up on the same side of the membrane, where they combine, producing water vapor (H_2O). The result: clean electricity and water. (*Adapted courtesy of Fuel Cells 2000, www.fuelcells.org.*)

advances by depositing sputter-coated nickel and copper-oxide catalysts onto the fuel processor's microchannels. A key objective—to obtain a high conversion of methanol to hydrogen—was met in 2003 when the team built a prototype that obtained almost complete conversion of methanol at about 270°C.

Some challenges still remain, including finding better ways to lessen the production of carbon monoxide, which poisons the fuel cell's PEM. The team, using a commercially available Preferential Oxidation or Prox catalyst, has eliminated the carbon monoxide in the fuel cell feed. They are developing a better catalyst that will lower the surface temperature of the fuel processor package to 40°C or less for military and consumer applications.

“Surface temperature is important for several reasons. For reconnaissance and intelligence gathering, a device that's hot enough to show up on heat-sensitive detectors is not acceptable,” says Upadhye. “And consumers would get nervous carrying an obviously warm device around in their pocket or purse. We don't want to add a lot of insulation, because that runs counter to the objective of keeping this power source small and compact. So we are exploring ways to lower the temperature of the reaction. We are also developing a vacuum packaging design for the fuel processor system.”

More Power in the Future

Although still experimental, the micro fuel cell project has drawn outside interest, and a Cooperative Research and Development Agreement is now in place with a company that has licensed the technology. Engineer Jeff Morse, head of the fuel cell project, explains, “We've developed fuel processors for easy storage of liquids such as methanol or butane. Those liquids can then be converted into hydrogen, which is notoriously difficult to store in any form. We now have a power plant on a chip that can be used for a variety of purposes, military and commercial.”

Upadhye adds, “Laptops need 10 to 15 watts, and we're working on reaching that threshold now. Someday, there will be a fuel cell that will, for instance, allow a laptop to run for days and days. Only a spare methanol cartridge, about the size of a cigarette lighter, will be needed to plug in when the first one goes empty. That day is not too far away.”

—Ann Parker

Key Words: Center for Microtechnology Engineering, fuel reactor, fuel reforming, hydrogen, methanol, micro fuel cell, micro fuel processor, microscale power source, proton-exchange membrane (PEM).

For further information contact Ravi Upadhye (925) 423-1299 (upadhye1@llnl.gov).